Rare B Decays
Standard Model @ LHC 2012,
Copenhagen, Denmark

Michelle Nicol, on behalf of the LHCb collaboration
(Some!) Rare B decay results from LHCb

Results presented here probe Flavour Changing Neutral Currents (FCNC)

- Forbidden at tree level in the SM
- Sensitive to new physics, as new particles could manifest in the loop, and cause deviations from standard model predictions. Can change branching fractions, angular distributions, CP violation.
- Indirect searches complimentary to direct searches at the GPDs.

With 1 fb\(^{-1}\) of LHCb data, collected in 2011:

- \(B_{d,s} \rightarrow \mu \mu\)
- \(B_{d,s} \rightarrow \mu \mu \mu \mu\)
- \(B^+ \rightarrow \pi^+ \mu \mu\)
- \(B^0 \rightarrow K^* \gamma : A_{CP}\)
- \(B^0 \rightarrow K^* \mu \mu\)
The LHCb detector

2x10^{11} B hadrons in LHCb acceptance in 2011
Excellent PID, efficient trigger, precision vertexing and tracking

other LHCb talks this conference
Jet measurements in LHCb and their relevance for pdfs: Marcin Kucharczyk
Electroweak results at LHCb: Katharina Mueller
Phi_s measurements: Conor Fitzpatrick
Gamma from B→DK: Sneha Malde
CPV in B→hh: Luigi Li Gioi
Charm results: Chris Thomas
$B_{d,s} \rightarrow \mu \mu$
**B_{d,s} \rightarrow \mu \mu: Analysis outline**

Branching ratios in SM predicted to be:

\[ BR(B_s \rightarrow \mu \mu) = (3.2 \pm 0.2) \times 10^{-9}, \quad BR(B_d \rightarrow \mu \mu) = (0.1 \pm 0.01) \times 10^{-9} \quad \text{A. J. Buras} \ [1,2] \]

Can be significantly enhanced by scalar and pseudo-scalar operators (MSSM, \( BR(B_s \rightarrow \mu \mu) \sim \tan^6 \beta \)).

At LHCb:

- Background reduced using a Boosted Decision Tree (Multivariate discriminant trained on MC using kinematical and geometrical variables (e.g., Vertex Chi2, impact parameters, direction between B momentum and direction, PT.).

- BDT response and mass PDFs are calibrated from data using \( B \rightarrow hh \) and dimuon resonances.

- Use three normalization modes. Allows for evaluation of different systematics, and the weighted average is used as final result.

- Divide the data into 8 bins of BDT output and 9 mass bins (optimised with MC toys).

- For each bin, compute the expected signal and background and count the candidates observed.

- Compatibility of observed distribution with given BR computed using CLs method [3]
Events observed with 1 fb$^{-1}$ at LHCb consistent with expected background and SM signal

More sensitive BDT bins

combinatorics
cross-feed

$B_{d,s} \rightarrow \mu \mu$

LHCb-PAPER-2012-007
Measure $\text{BR}(B_s \to \mu \mu) < 4.5 \times 10^{-9}$ and $\text{BR}(B_d \to \mu \mu) < 1.03 \times 10^{-9}$ at 95% C.L.

cf $\text{BR}(B_s \to \mu \mu) < 7.7 \times 10^{-9}$ [CMS-BPH-11-020] 5 fb$^{-1}$

$\text{BR}(B_s \to \mu \mu) < 22 \times 10^{-9}$ [ATLAS-CONF-2012-010] 2.4 fb$^{-1}$

By performing a simultaneous maximum likelihood fit to the mass distributions in the 8 BDT bins, estimate branching fraction to be $\text{BR}(B_s \to \mu \mu) = (0.8^{+1.8}_{-1.3}) \times 10^{-9}$

Increasingly constrains SUSY parameter space
\[ B_{d,s} \rightarrow \mu \mu \mu \mu \mu \]
The observed events are consistent with the expected background yield. First limits on branching fractions:

\[ BR(B_s \rightarrow \mu \mu \mu \mu) < 1.3 \times 10^{-8} \]

\[ BR(B_d \rightarrow \mu \mu \mu \mu) < 5.4 \times 10^{-9} \]

at 95% C.L.
$B^+ \rightarrow \pi^+ \mu \mu$
No $b \to d \ell^+ \ell^-$ transition has previously been observed.

In SM, it is suppressed by a factor $|V_{td}/V_{ts}|^2$ relative to $b \to s \ell^+ \ell^-$

Can envisage new physics models where this suppression doesn’t apply.

In SM, $BR(B^+ \to \pi^+ \mu \mu) = (1.96 \pm 0.21) \times 10^{-8}$ S. Hai-Zhen, L/ Lin-Xia and L. Gong-Ru [7]

Observe 25 $^{+6.7}_{-6.4}$ events with 5.2σ significance.

$$BR(B^+ \to \pi^+ \mu \mu) = (2.4 \pm 0.6 \pm 0.2) \times 10^{-8}$$

The rarest B decay ever observed.
$B^0 \rightarrow K^*\gamma$
The theoretical uncertainty on the SM prediction of direct CP asymmetry is smaller than that on the branching ratio prediction

$$A_{CP}^{SM}(B^0 \rightarrow K^{*0} \gamma) = -0.0061 \pm 0.0043 \ \text{Y. Y. Keum, M. Matsumori and A. I. Sanda}[8]$$

Extract raw asymmetry from unbinned simultaneous fit to the mass distributions of $B^0$ and $\bar{B}^0$ candidates.

$$A_{CP}(B^0 \rightarrow K^{*0} \gamma) = -0.008 \pm 0.017 \pm 0.009 \ \text{(LHCb preliminary)}$$

cf. previous best measurement from BaBar: $A_{CP} = -0.016 \pm 0.022 \pm 0.007 \ [9]$
$B_d \rightarrow K^* \mu \mu$
$B_d \rightarrow K^* \mu^+ \mu^-$: Angular analysis

Fully described by three angles, $\theta_L$, $\theta_K$, $\Phi$ and $q^2 = \text{Mass}^2(\mu \mu)$.

Performing angular analysis with 1 fb$^{-1}$ of 2011 data measure the following parameters: [10]

- $A_{FB}$ Forward backward asymmetry of dimuon system
- $F_L$ Fraction of longitudinal polarisation of the $K^*$
- $S_3$ Transverse asymmetry
- $A_{im}$ T-odd CP asymmetry

And also differential branching ratio.

Gives access to $C_7^{(*)}$, $C_9^{(*)}$, $C_{10}^{(*)}$
$B_d \rightarrow K^* \mu \mu$: Angular analysis

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At LHCb, use BDT to reduce combinatorical background, and PID for peaking backgrounds.

Analysis sensitive to angular acceptance. Care taken to avoid bias: No PT used in BDT

Observe 900 candidates (BaBar+Belle+CDF ~600 events)

Angular acceptance from detector corrected using simulation.
$B_d \rightarrow K\pi \pi$: Angular analysis results

- $A_{FB}$ and $S_3$ shown in backup
- Points include both statistical and systematic uncertainties
- Systematic uncertainties typically small compared to statistical
- Theory predictions found in [11]

Most precise measurements of these quantities to date and fully consistent with SM predictions
In SM, $A_{FB}(q^2)$ changes sign at well defined $q_0^2$, free from form-factor uncertainties. This is estimated by extracting the $q^2$ distribution for the forward- and backward-going candidates separately, using unbinned fits to $m_{B_0}$ and $q^2$.

The red hatched area is 68% confidence level on observed zero crossing point.

- world's first measurement: $q_0^2 = 4.9^{+1.1}_{-1.3}$ GeV (LHCb preliminary)
- SM predictions range from 4.0-4.3 GeV [12-14]
World’s most precise measurements:

- $B_{d,s} \to \mu \mu$
  
  Best limits to date
  
  Also measured (see charm talk by Chris Thomas) $D \to \mu \mu$ limits
  
  Coming soon: $K_s \to \mu \mu$

- $B_\mu \to \mu \mu \mu \mu$
  
  First limits

- $B^* \to \pi^+ \mu \mu$
  
  First branching fraction measurement

- $B^0 \to K^* \gamma$
  
  direct CP asymmetry
  
  Coming soon: updated result with 1 fb$^{-1}$ of $BR(B^0 \to K^* \gamma) / BR(B_s \to \Phi \gamma)$

- $B^0 \to K^* \mu \mu$
  
  angular variables
  
  zero crossing point
  
  branching fraction
  
  Also measured $B_s^0 \to \Phi \mu \mu$ branching fraction
  
  Coming soon: Isospin asymmetry, $B^0 \to K^* \mu \mu$, $B^+ \to K^+ \mu \mu$, $B^0 \to K_s \mu \mu$, $\Lambda_b \to \Lambda^* \mu \mu$...
### References

7. S. Hai-Zhen, L/ Lin-Xia and L. Gong-Ru, Communications in Theoretical Physics **50** (2008) 696
Backup
\( B_d \rightarrow K^* \mu^+ \mu^- \): Angular analysis results

**LHCB-CONF-2012-008**

\( A_{1m} \sim O(10^{-3}) \) in SM
$B_d \rightarrow K^* \mu \mu$: Angular analysis results

LHCb-CONF-2012-008